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A peer-to-peer non-line-of-sight localization system scheme in GPS-denied scenarios

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14. ABSTRACT

Under this project, a novel non-line-of-sight (NLOS) localization technique based on the concept of virtual reference device has been developed and tested experimentally in an indoor multipath environment. As compared to the conventional line of Sight (LOS) localization techniques which need at least three references devices (RD) with known locations in direct line of Sight (LOS) with the unknown mobile device (MD), the developed NLOS localization technique need just one RD to localize the unknown MD without the need of LOS and external references. In other words, it allows peer-to-peer NLOS localization in GPS denied scenarios. This is feasible through the use of virtual reference devices. The position of virtual reference device for each NLOS path can be determined if the initial MD position can be estimated or when the MD transits from LOS to NLOS region. With the position of virtual reference devices, the subsequent localization of MD requires only one signal path. Simulation and experiment conducted in indoor multipath environment show that the performance of the developed NLOS localization technique surpasses the existing localization schemes by a significant margin at all simulated and measured locations by using just one RD and one dominant path. This piece of work has been published in IEEE Antennas and Wireless Propagation Letters.

15. SUBJECT TERMS

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Final/~~Annual~~/~~Midterm~~ Report for AOARD Grant FA2386-12-1-4024

"**A peer-to-peer non-line-of-sight localization system scheme in GPS-denied scenarios**"

Date 9/24/2014

Name of Principal Investigators (PI and Co-PIs): Assoc Prof Tan Soon Yim, Assoc Prof Guan Yong Liang and Dr. Seow Chee Kiat

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Abstract: Short summary of most important research results that explain why the work was done, what was accomplished, and how it pushed scientific frontiers or advanced the field. This summary will be used for archival purposes and will be added to a searchable DoD database.

Under this project, a novel non-line-of-sight (NLOS) localization technique based on the concept of virtual reference device has been developed and tested experimentally in an indoor multipath environment. As compared to the conventional line of Sight (LOS) localization techniques which need at least three references devices (RD) with known locations in direct line of Sight (LOS) with the unknown mobile device (MD), the developed NLOS localization technique need just one RD to localize the unknown MD without the need of LOS and external references. In other words, it allows peer-to-peer NLOS localization in GPS denied scenarios. This is feasible through the use of virtual reference devices. The position of virtual reference device for each NLOS path can be determined if the initial MD position can be estimated or when the MD transits from LOS to NLOS region. With the position of virtual reference devices, the subsequent localization of MD requires only one signal path. Simulation and experiment conducted in indoor multipath environment show that the performance of the developed NLOS localization technique surpasses the existing localization schemes by a significant margin at all simulated and measured locations by using just one RD and one dominant path. This piece of work has been published in IEEE Antennas and Wireless Propagation Letters.

Introduction: Include a summary of specific aims of the research and describe the importance and ultimate goal of the work.

Conventional Localization techniques require at least three RDs in LOS with MD. These conventional LOS localization techniques rely on the triangulation of the LOS paths between RDs and MD. They are based on the measured distance (e.g. Time of Arrival (TOA) between the RD and MD). It also requires at least three LOS paths to determine MD location. However, NLOS paths between RDs and MD can be mistakenly used and will result in large localization error. Conventionally, there exits NLOS path mitigation techniques to minimize the contribution of NLOS paths and identify the LOS RDs to be used for localization. However, in general, these mitigation techniques require number of RDs in LOS with MD be greater than the number of RDs in NLOS with MD. This requirement is challenging to meet in indoor multipath environment. For existing NLOS localization techniques, the estimated MD location can be found with at least two dominant one-bounce NLOS paths but in some GPS-denied indoor environments, there may exist insufficient number of one-bounce NLOS paths and dominated by multiple-bounce NLOS paths. Furthermore, existing NLOS localization techniques that leverage on line of possible mobile location (LPMD) may suffer from parallel line intersection of these LPMDs, which results in poor estimation of MD location.

Under this project, a NLOS localization technique that overcomes the above LOS and NLOS localization techniques' limitations using just one RD and one single dominant NLOS path has been developed and significantly improved the localization accuracy by using the concept of virtual RD to determine MD location. The position of virtual RD for a given NLOS path can be determined by

initial guess of the MD location. Alternatively, the virtual RD location can also be found if the MD transits from LOS to NLOS region. After the positions of all virtual RDs are identified, the subsequent MD location can be determined by using just one dominant NLOS path and its corresponding virtual RD. The performance of the developed NLOS localization technique is evaluated using simulation and experiment conducted in an indoor environment. The results show that the developed NLOS localization technique outperforms existing localization schemes by a significant margin for all simulated and measured locations.

Experiment: Description of the experiment(s)/theory and equipment or analyses..

Description of Theory

With the initial estimation of MD location and the TOA and angle of arrival (AOA) of each NLOS path that is associated between a RD and MD, the corresponding likelihood area of the virtual RD originated from both RD and MD can be derived. Through the overlapping of these two areas, the estimated position of the virtual RD associated with each NLOS path can be found. The virtual RDs for all other NLOS paths can be determined similarly. When the MD moves to a new location, the virtual RD that corresponds to the dominant NLOS path at a new location can be found using measured TOA and AOA of that path. Based on the measured TOA, AOA, and the corresponding virtual RD, the new MD location can be determined.

Description of Experiment

The localization experiment is conducted in an indoor environment at Internet of Things (IoT) laboratory at School of Electrical and Electronics Engineering (EEE), Nanyang Technological University (NTU). Channel measurement between a RD and MD is collected using Vector Network analyzer (VNA) that sweeps frequency from 2 GHz to 3 GHz as the MD transits from point to point for a total of 7 MD points. Both RD and MD are equipped with a 4x4 antenna array. TOAs and AOAs of the signal paths that transverse between the RD and MD at these 7 MD points are parametrically estimated using the collected channel measurement. The estimated TOA and AOA were then fed into the developed NLOS localization technique and compared with the existing LOS and NLOS localization techniques. To assess the performance of the developed NLOS localization technique robustly, simulation is also conducted in an indoor environment using the same dimension as the IoT with obstacles randomly distributed and exponential distributed NLOS path. The average location error (ALE) is obtained with uniformly distributed MD location within the simulated environment. Further detail of the experiment and simulation are articulated in the published IEEE journal.

Results and Discussion: Describe significant experimental and/or theoretical research advances or findings and their significance to the field and what work may be performed in the future as a follow on project. Fellow researchers will be interested to know what impact this research has on your particular field of science.

The experimental average root mean square (RMS) error of the developed NLOS localization technique for the 7 MD location points is calculated to be 1.6 m as compared to the average RMS error of 21.3m for one of the existing NLOS localization techniques. Furthermore, the ALE obtained for the developed NLOS localization technique based on one RD achieves ALE of less than 2 metres, outperforming all existing LOS and NLOS localization techniques used for comparison in the simulation. Existing LOS and NLOS localization techniques achieve ALE of at least 8.7m and 15m respectively.

Based on the experimental and simulation results, we have shown that the developed NLOS localization technique using just one RD is able to outperform existing localization techniques and overcome their limitations but also enabled the capabilities to track the MD in the GPS denied environment using any available dominant path.

List of Publications and Significant Collaborations that resulted from your AOARD supported project: In standard format showing authors, title, journal, issue, pages, and date, for each category

list the following:

a) papers published in peer-reviewed journals,
b) papers published in peer-reviewed conference proceedings,
c) papers published in non-peer-reviewed journals and conference proceedings,
d) conference presentations without papers,
e) manuscripts submitted but not yet published, and
f) provide a list any interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work.

a) S.W. Chen, C.K. Seow and S.Y. Tan, "Virtual Reference Device-based NLOS Localization in Multipath Environment", *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1409-1412, 2014

Attachments: Publications a), b) and c) listed above if possible.

DD882: As a separate document, please complete and sign the inventions disclosure form.

Important Note: If the work has been adequately described in refereed publications, submit an abstract as described above and refer the reader to your above List of Publications for details. If a full report needs to be written, then submission of a final report that is very similar to a full length journal article will be sufficient in most cases. This document may be as long or as short as needed to give a fair account of the work performed during the period of performance. There will be variations depending on the scope of the work. As such, there is no length or formatting constraints for the final report. Keep in mind the amount of funding you received relative to the amount of effort you put into the report. For example, do not submit a $300k report for $50k worth of funding; likewise, do not submit a $50k report for $300k worth of funding. Include as many charts and figures as required to explain the work.